General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

EPRI Approach to Yucca Mountain Performance Assessments –

A View from the Outside

John Kessler
Manager, HLW and Spent Fuel Management Program, EPRI, Inc.
+1-650-855-2069; jkessler@epri.com

EPRI's Role at Yucca Mountain

- EPRI performs technical analyses for the electric utilities
- US nuclear utilities pay a "tax" for DOE to receive and manage their spent fuel
  - Nuclear Waste Fund: ~$800 million per year
  - DOE to receive and manage, NRC is regulator
  - Industry asks EPRI to inform and influence

EPRI Yucca Mountain Program is Small (compared to DOE and NRC)

- DOE: $300 – 500 million per year
- NRC: ~$10 million per year
- EPRI: $0.5-$1.8 million per year
- Forces EPRI to:
  - Stay focused on the most important issues
  - Use as much information generated by others as possible
  - Use considerable "expert judgment" for:
    - Development of models
    - Selection of data

General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

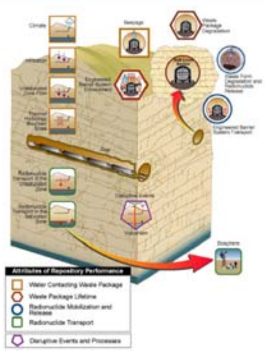
Most Important Issue for EPRI

- Make sure NRC and DOE focus on those issues most important to overall safety
  - Role of TSPA critical in being able to prioritize
  - Industry asks EPRI to develop their own TSPA model

General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

Total System Performance Assessment (TSPA) View

- **What we are asked to do:**
  - **Model a large, complex, system with limited data**
  - **Predict what will happen over 10^4 to 10^6 years**
- **What we do:**
  - **Simplify into a set of features that affect:**
    - **When waste gets out**
    - **How much gets out**
    - **Concentration in the groundwater**



General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

Total System Performance Assessment (TSPA) Model is EPRI's Main Tool

- 1989-90: EPRI demonstrated that TSPAs can be done
  - Before 1989:
    - Many models of pieces of the system, but no clear idea how important each piece was
    - Affected the nature of the regulation ("subsystem performance criteria")
- EPRI TSPA team covers the following:

– Climatology	- Soil science
– Hydrogeology	- Mining engineering
– Materials science	- Nuclear engineering
– Heat transfer	- Geochemistry
– Seismicity	- Volcanology
– Radioecology	- Health physics

General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

Major Factors that Affect Long-Term Safety

Two factors reduce the individual radiation dose rate (millirem/yr):
- **Time (allows for radioactive decay)**
- **"Dilution" (including slow release rates)**

- **How much groundwater contacts how many containers?**
- **How fast do the engineered barriers fail?**
- **How long does it take groundwater to get the waste out to the biosphere?**

- ***Answers to these questions are treated probabilistically***

Types of "Uncertainty"

- Natural variability
- Randomness
- Measurement error
- Conceptual model uncertainty
- Typically, performance assessments do not distinguish between the first three
- Conceptual model uncertainty treated separately (sometimes)
  - Option 1: keep alternative models separate
  - Option 2: expert elicitation (then use distribution)

Keeping Track of Uncertainty in a *Total* System Performance Assessment is a Challenge

- Subsystem models roll into the total system model
  - Example: When and where does the waste (spent fuel) get exposed to groundwater?
    - Rainfall ⇒ Evaporation/runoff ⇒ Net infiltration (soil and rock properties)
    - Net infiltration ⇒ Deep percolation (rock properties, radioactive decay heat) ⇒ Seepage into the tunnel (rock and backfill properties, decay heat)
    - Groundwater chemistry ⇒ Drip shield and container degradation modes (potentially many!) ⇒ Drip shield and container failure rates and geometries
    - Groundwater and in-package chemistry ⇒ Spent fuel cladding properties ⇒ Cladding failure rates
  - Each one of these has many aspects of uncertainty

Methods of Handling Subsystem Model Complexity and Uncertainty

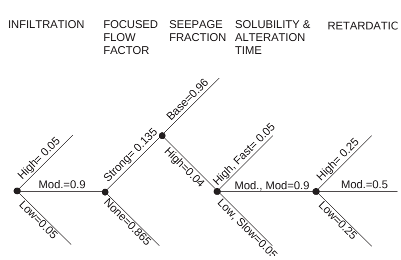
- Use all submodels and uncertainties “as is”
  - Huge, complex computer model
  - Loss of “transparency”
  - BUT, keeps track of all uncertainties directly
- Use “abstracted” (simplified) models
  - Example: roll up all the groundwater flow models above the repository into a single “lookup table”
    - Probability and spatial distribution of groundwater entering the tunnels
  - Simpler, more “transparent” model
  - Some details of what causes behavior and uncertainty distributions are lost

Two Approaches to Probabilistic Modeling Used

- Monte Carlo sampling (most common)
  - Every parameter and model (of importance) assigned an uncertainty and/or variability distribution
    - Some distributions dependent on others
  - “Roll the dice”: randomly select from the entire suite of distributions and calculate the result
    - Some entire models are sampled separately, then “hard-wired” (e.g., complex groundwater flow models)
    - Sample and recalculate hundreds to thousands of times, then determine statistics

EPRI Uses a Logic Tree Approach to Probabilistic TSPA (i.e., not Monte Carlo)

- Limited number of branches with discrete probability and parameter value for each branch



Some Information “Abstracted” into “Lookup Tables”

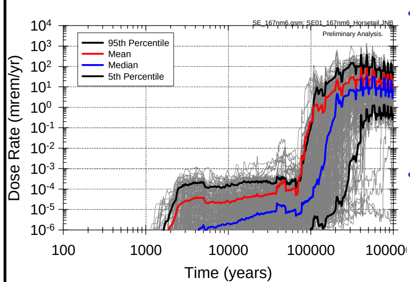
Infiltration Rates example [mm/yr]

Climate	Low	Mod.	High
Greenhouse (0-1000 years)	1.1	11.3	19.2
Interglacial (1000-2000 years)	1.1	7.2	9.6
Full Glacial Maximum (beyond 2000 years)	6.8	19.6	35.4

General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

Example of a Monte Carlo “Horsetail” Diagram”

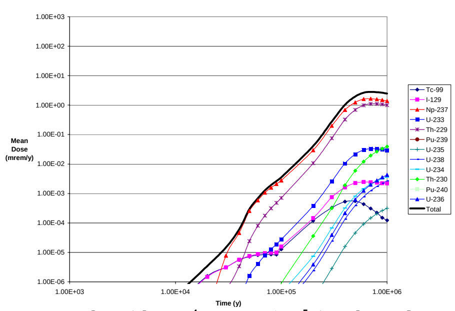
(from DOE Results presented 9/02 to NWTRB - Nominal Performance)



- 300 realizations shown for two repository designs, with 95^{th}, 50^{th}, and the mean annual dose (5^{th} percentiles off-scale)
- Red curve is “mean”
  - Median in blue
  - 5^{th} and 95^{th} percentiles in black
  - Mean is often near 95^{th} percentile

General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

Means of the Distribution by Radionuclide (EPRI 2003 nominal performance results shown)

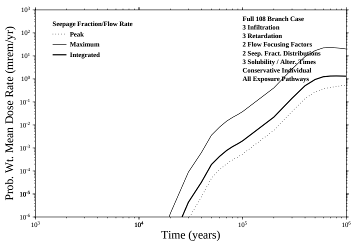


Peak 10,000-year dose risk: ~10^{-4} mrem/yr (~10^5 times lower than NRC limit)
Peak 1,000,000-year dose risk: 3 mrem/yr (~1% of natural background dose)

General Training On Methodologies For Geological Disposal in North America
IAEA Network of Centers of Excellence

Look at Individual Realizations (or Smaller Groups) for More Specific Insight

- Provides understanding of which parts of the system contribute the most to dose risk
- Fix parameter/model and let all else vary
  - Redo for other fixed values
- Statistical tests also used to determine most important parameters/models



NRC Requires Multiple "Barriers" for Yucca Mountain

- NRC definition: "any material, structure, or feature that … prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or prevents the release or substantially reduces the release rate of radionuclides from the waste"
- At least one "natural" and one "engineered" barrier required
- Note: NRC definition is *not* in terms of dose or health risk
  - Therefore, these are indirect measures of importance to health protection

Barriers EPRI Considered

- "Natural":
  - Unsaturated Zone (UZ) Above Repository (retention, limits release rates)
  - Percolation Rates/Solubility Limits (limits release rate)
  - UZ Below Repository (limits transport)
  - Saturated Zone (SZ) (limits transport)
- "Engineered":
  - Waste Form (limits release rate)
  - Cladding (retains, limits release rate)
  - Container (retains, limits release rate)
  - EBS components (sorption, diffusion – limit release rates)

Two Ways to Look at Barriers

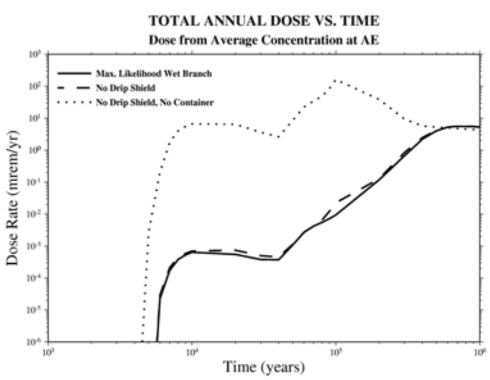
- "Reduce" or "limit" analyses
  - Retention or delay time
  - Release rate
  - Do for individual radionuclides and then for all
  - Calculate radionuclide release rates versus time

- Purely theoretical "barrier neutralization" analyses
  - Assume barrier does not function as expected
  - Calculate theoretical dose rates versus time

Example of "Reduce" or "Limit" Analysis: Drip Shield, Container, Cladding Retention

- Time to 50% failure (and compare to radionuclide half-lives):
  - Drip shields: ~70,000 years
  - Containers: >1,000,000 years (30% failed at 1Myrs)
  - Cladding: ~25,000 years
- Peak fractional failure rates (correlate better to peak dose risks):
  - Drip shields: ~10^{-4} per year
  - Containers: ~10^{-7} per year
  - Cladding: ~10^{-4} per year

Example of Barrier Neutralization:



Conclusions from Barrier Analyses

- Many barriers can contribute substantially to “performance”
- The amount of performance depends on what other barriers are assumed
  - A “strong” barrier can mask a “weaker” barrier
  - Example of “defence-in-depth”

Conclusion: MANY Approaches to TSPA

- Deterministic
- Probabilistic: Monte Carlo and Logic Tree
  - Mix or separate uncertainty types (randomness, variability, etc.)
  - Present all realizations (horsetail diagrams) along with mean and percentiles
  - Statistical and sensitivity analyses to understand correlations and dependencies
- Barrier analyses
- Differing methods yield different insights
- Quantifying uncertainties somewhat controversial
  - Active area of study

Recommendations for Those Just Starting Performance Assessments (on a limited budget!)

- Use whatever you can produced by others that is relevant
  - Especially necessary if no site has been selected
- Do not substitute conservative models for uncertainty (unless you have NO other choice)
  - Conservative models skew the results ***(understanding the important parts of the system is critical!)***
  - Use expert judgment if you must
- Do not make your model so complex that you do not understand or cannot explain your results
  - You want technical insight FIRST before decision-making
  - Complexity can be added later when required
- Try both deterministic and probabilistic approaches

Recommendation for Those Developing Siting Criteria

Do not develop too many detailed criteria!

- Examples of detailed criteria to avoid:
  - Minimum groundwater travel time to the biosphere
  - Maximum fractional release rate from the repository
  - Sites with “stable” geology that are not “complex”
    - However, geologically complex sites will cost more to characterize
    - On the other hand, one won’t find all the “complexity” until detailed investigations begin (all sites are somewhat “complex”)
- Will be nearly impossible to find a “perfect” site
  - Best to have many choices early on
  - “Performance” comes from many parts of the system
  - Repository design can be optimized to take advantage of the specific details of the geologic system selected
    - Use of backfill, container materials, etc.